–Development of Measuring technique for Electric Power of Wind turbine-Solar Photovoltaic hybrid system

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Summary- *This paper discusses the construction and implementation of a system for the measurement of electrical power parameters; amperage and voltage of the hybrid system photovoltaic solar-wind, to evaluate the system parameters and performance. The basis of the development of the measuring apparatus is the use of an Arduino Mega 2560 to provide the interface between the electrical circuits of the sensors and the dynamics of the voltage-amperage as well as collect data in an analog format as well as development of functional dependence relationships. The collected data is converted into digital format and stored it in an Excel format through the "PLX-DAQ Spreadsheet" that connects the Arduino and the PC for display and analysis of the system parameters. The proposed technique for power measurements of AC and DC proved to be reliable and can predict the power amperage and voltage within relative error of 1.63 % for AC and 4.16% for DC, respectively.*

I. Introduction

The global need to conserve the planet, energy and satisfy the continuous demand for electrical energy generation has led us to explore new sources of sustainable energy such as solar and wind as well as other sustainable energy sources.

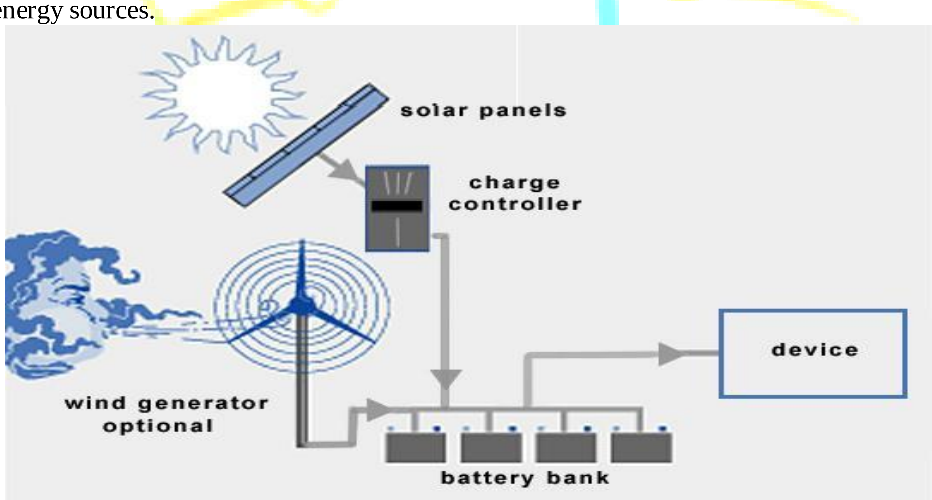

Fig. 1: Schematic of a photovoltaic Hybrid System [1].

The photovoltaic wind hybrid system as shown in Figure 1, is a system that can be integrated into two or more renewable sources of energy (solar-thermal, geothermal, biomass, hydro etc.). Those systems are integrated to provide electricity or heat, or both, to supply the demand, and taking advantage of the availability of solar and wind energy, in places where these two sources of renewable energies are complementing to each other [2]. Interested readers are advised to consult reference [2] on the subject.

The wind energy depends on the conditions of the wind and ambient conditions, the wind turbine is recommended where average annual wind speeds are higher than 6.5m/s at a height of 50m.

On the other hand, photovoltaic energy has been one of the renewable energy sources with rapid technological growth. It has been reported that its annual production of solar panels grew tenfold from 1990 to 2003 (50 MW to 500 MW), and is in constant growth [3]. The function of the photovoltaic solar panel is simple; solar panels receive solar radiation form of light and thus generate a potential difference at its ends in the form of continuous current. These panels are normally connected in parallel or series depending on the power and load requirements.

It should be noted that a hybrid system such as solar/wind hybrid must have load/charge controller which controls the wind turbine and solar panel at the same time and allows the conversion and transformation

of wind and solar energies into electrical energy and consequently, stores this electrical energy in the batteries bank. It should be also noted that the driver of the hybrid Wind/Solar is the most important part in the out-of-network system, due to the control that allows the operation of all the hybrid system [4].
This paper is intended to discuss the construction and implementation of a system for the measurement of electrical power parameters such as amperage and voltage of the hybrid system; photovoltaic solar-wind, to evaluate and analyze the system performance.

II. Photovoltaic-Wind Hybrid System:

The Photovoltaic system.

The photovoltaic solar panel converts the solar energy into electrical energy and the use the solar panels are considered as renewable energies, increasingly widespread and accepted as previously discussed. The energy output from Photovoltaic is influenced by different variables of the solar panel such as the material of the cells, cell temperature, cells connection, and the atmospheric conditions. The process of electro dialysis of photovoltaic depends on the constructive and operational variables of the solar panel as discussed and analyzed in reference [5].

Fig. 2: Photovoltaic Panel. Laboratory (CER)

The Photovoltaic system under investigation has two photovoltaic solar panels as shown in Figure 2. The solar panels are made up of single crystals, and each has 36 cells from 0.5 volts to open circuit and 7 A. in closed circuit; the cells of the solar panel are connected in series so that a voltage of 18V can be obtained. Each solar panel was designed to supply power to an electrical load of 120 watts and also provide enough power to charge a batteries bank.

Mono crystalline cells are formed by a single type of silicon crystal, and have been manufactured from glass, that controlled the growth of its own silicon crystal and can be only formed in one direction, resulting a fairly perfect alignment of all components of the glass [6]. Interested readers in the process and the subject are advised to consult reference [6].

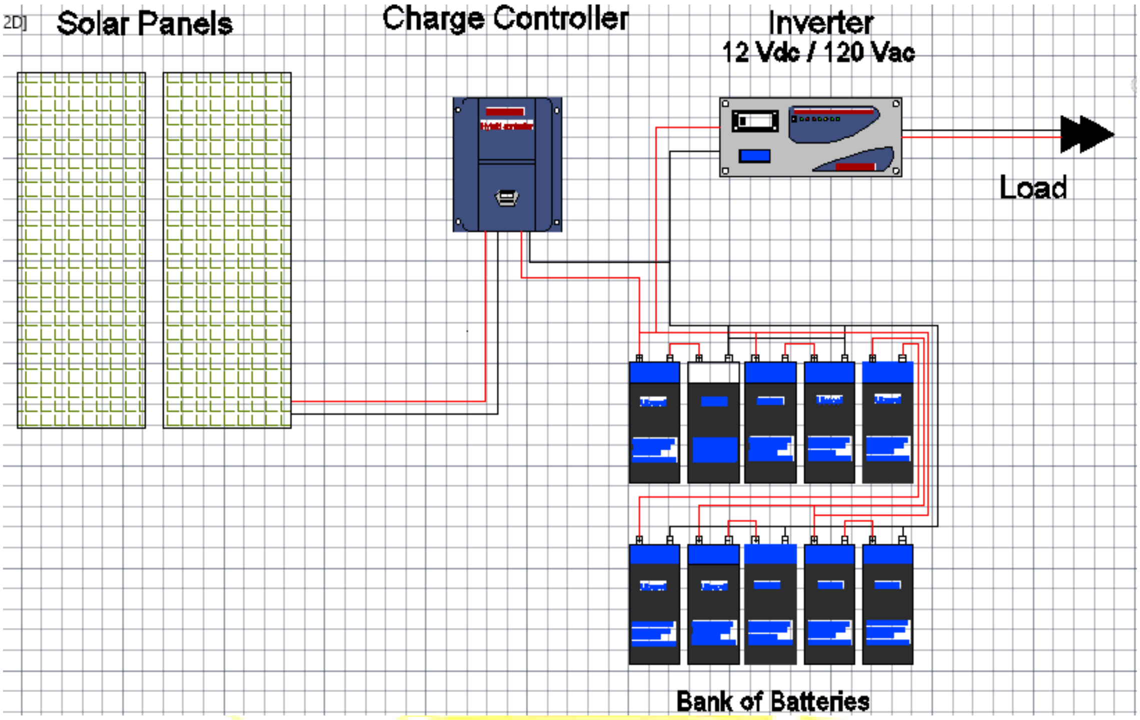

Figure 3: Internal Circuit of PV. Laboratory (CER)

The performance of the solar panels under investigation is specified in the technical sheet provide by the supplier which is based upon conditions in a laboratory at 25ºC and with a solar radiation of 1,000 W/m² [6]. It is important to optimize the solar panel performance. This can be determined from technical sheet of the photovoltaic panels, or by a simple calculation of the solar radiation in W/m², of the panel in each case and determine the output power. To determine the intensity of solar radiation, the solar radiation in watt absorbed by solar panel is divided by the area in square meters of the panel [6].

The Photovoltaic solar panels have the positive (+) and negative (-) points at the rear for connection and wiring. It is important to point out that solar photovoltaic panels generate direct current (DC), which can be transformed into alternating current, (AC) by inverter as shown in Figure. 3. In the laboratory CER (Research Center for Renewable Energy) the inverter shown in Figure.4 has been used in this study and has an input of 24 V DC and 120 V AC output of 2000W at 60Hz.

Fig. 4: Inverter. Laboratory (CER)

Principle of Electric Power Generation:

In metals, electrons move freely through the crystalline grid, these electrons do not escape the metal at normal temperatures conditions, because they don't have sufficient energy. Heating the metal is one way to increase their energy. The electrons are called "Thermo Electron". In the photoelectron spectroscopy, electrons are released through the absorption of the energy of electromagnetic solar radiation by the metal. This principal of releasing photoelectron spectroscopy has been discussed in details in reference [7]. Interested readers in the subject are advised to consult this reference and others on the subject. As pointed out, the solar radiation received by the solar panel is converted into electrical energy in DC and is stored in a batteries bank as can be seen in Figure. 5.

Fig. 5: Bank of batteries. Laboratory (CER)

Wind Energy

Wind energy is generated by the kinetic energy of the wind induced by the wind velocities, and this kinetic energy is converted into mechanical energy and electrical energy in a wind turbine. Figure.6 shows the different parts of a wind turbine [2] and illustrates the energy conversion principal as explained in reference [2]. The wind comes from the Latin term Aeolicus, or pertaining to Aeolus or Aeolus, the God of the winds in Greek mythology, pertaining to the wind. The operation of the wind turbine is extremely simple; the wind force is applied on the blades, and consequently, the wind turbine blades rotate, this movement of rotation is transmitted to the generator through a speed multiplier system. The generator will produce electrical current that is transmitted to the lines of transmission lines, as illustrated in Figure.6. To ensure continuous electrical supply, it is necessary to have accumulators to ensure at all times the electrical supply [8].

The wind energy and kinetic energy generation mainly depends on 3 factors:
1. Area where the wind goes (rotor)
2. Air Density
3. Wind Speed

In the following the different components of the wind turbines are described;

The rotor

It is the element that transforms the kinetic energy of the wind into mechanical energy. In turn, the rotor is composed of three basic parts: the paddles, the shaft (which transmits the rotary motion of the blades to the wind turbine) and the hub (that secures the blade to the shaft). The blades are the most important elements of the wind turbine, as they convert the force of the wind into a mechanical energy. They are made with polyester resin and glass fiber on a resistant structure, and its size depends on the technology used and the speed of the wind [8].

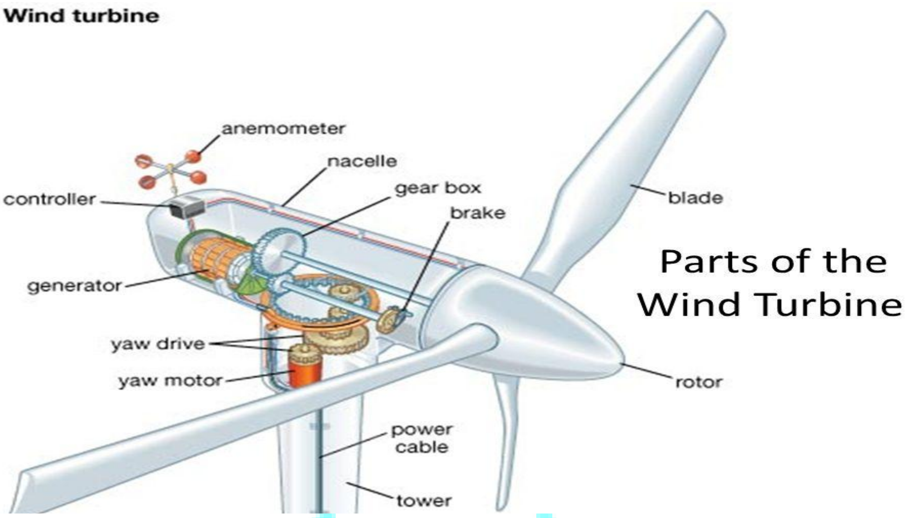

Fig. 6 Parts of a wind turbine [2]

Multiplier

This element is connected to the rotor which multiplies the speed of rotation of the shaft to achieve the high number of revolutions needed by the dynamos and alternators. The multipliers are distinguished by two types: the toothed pulleys and gear· Toothed Pulleys multipliers are used for rotors of low power·

Gear Multiplier

In this type of gear multiplier, the gears are protected in boxes shielded to prevent misalignment and degreasing. Although most of the wind turbines have multiplier, there are some rotors that do not need it.

Generator

The function of the generator is to transform the mechanical energy into electrical energy.
Sizes of the generators depend upon the power of the wind turbine are well discussed in [8].

Gondola

The gondola is the structure in which the basic elements of conversion of energy are housed; the rotor shaft, multiplier, generator and auxiliary systems.

Tower

The tower is the clamping element where the rotor and the mechanisms are mounted. It is built on a base of reinforced concrete (foundations) and secured with bolts. The tower has tubular form and must be durable enough to withstand all the weight and the force of the wind, snow, and other climate conditions. It houses the electrical cabinet, through which it acts on the elements of generation and that contains all of the cabling system that comes from the gondola, as well as the transformer that raises the voltage. The exterior has scales to have access at the top [8].

Types of wind turbine

The most commonly wind turbines are used horizontal axis wind turbines. They must be held parallel to the wind direction, to avoid impact on the paddles and rotate the shaft. These types of wind turbines can be:

Low or medium power (0 to 50 kW): often have many blades (up to 24).They are used in the rural environment and as a complement for housing.
High power (more than 50 kW): Usually have a maximum of four blades of aerodynamic profile, although they usually have three. Need winds of more than 9 m/s. It has industrial use, provided in parks or wind. [8]

Vertical axis wind turbines: its technological development is less advanced than the previous ones and their use is limited, although it has growth prospects. Do not need guidance and offer less resistance to the wind.

Technical specifications of the wind turbine

Table.1 outlines a typical specification of a wind turbine used in our study. In addition, Figure.7 shows the typical wind turbine performance curve employed in this study. The wind turbine used in this study has a

power output of 1.8 kw to 56 VDC. In addition, Fig. 8 illustrates the wind turbine basic setup schematic diagram used in this study.

Rotor Diameter	3.2m
Material and number of blades	3 reinforced fiberglass blades
Nominal power/ Maximum power	1.5kw / 1.8kw
Nominal wind speed	9m/s
Start of wind speed	2.5m/s
Working wind speed	3-25m/s
Maximum wind speed	50m/s
Operating voltaje	DC 24 / 48V
Type of generator	Three phase / Permanent magnet
Load	Constant voltaje
Height of the tower	12m
Time of life	10-15 years

Table 1 specifications of the Wind Turbine

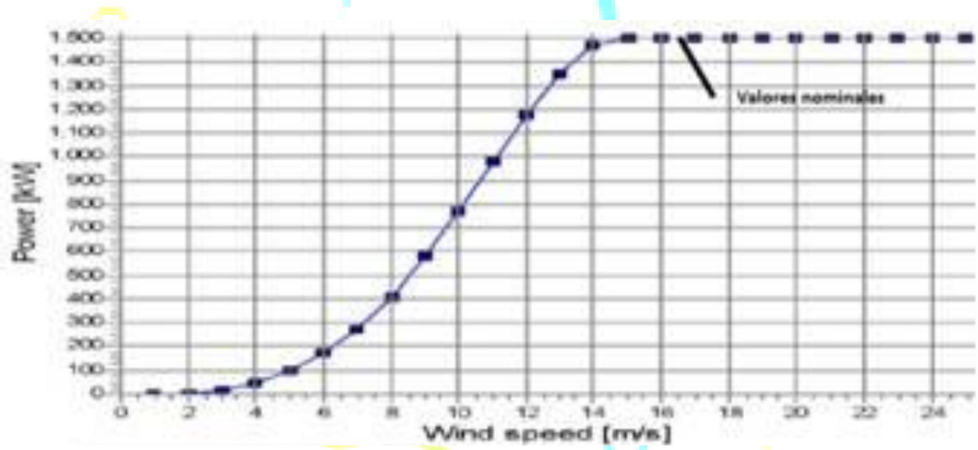

Fig. 7 Performance of the turbine

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RPM	OPEN CIRCUIT VOLTAGE DC (V)	WORK VOLTAGE DC (V)	CURRENT DC (A)	OUTPUT POWER DC (W)
155	56			
175	69	56	5.1	285.6
201	79	56	8.8	492.8
241	92	56	12.7	711.2
283	109	56	18.4	1030.4
329	126	56	22.8	1276.8
379	144	56	26.4	1478.4
422	160	56	28.7	1578.5
481	181	56	30.6	1713.6

Table 2 specifications of Wind Turbine

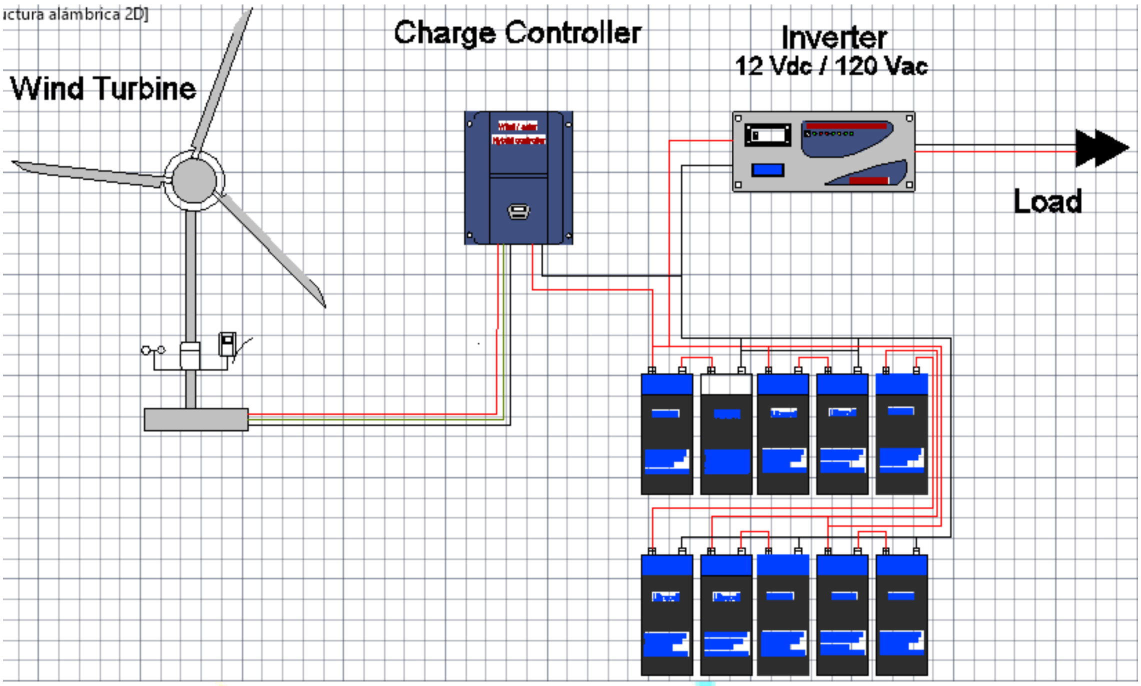

Fig. 8 Wind Turbine

The wind turbine employed in this study was installed at the top of a high tower of 10m of height. The combined wind turbine- photovoltaic hybrid system, thus, can deliver 2000 W. The measurement system described hereby was built to accommodate such power capacity.

Measurement Systems

To monitor the voltage and amperage and consequently power of the hybrid system of PV-Wind, electrical circuits that monitor the variations of voltage and amperage of both solar panel and Wind turbine were built and connected to the Arduino Mega 2560. It was taken into account that the analog data is received and must compatible with the Arduino Mega 2560. The input data to the Arduino fluctuates between a minimum of 0 volts and a maximum of 5 volts, and the pins that receive data are analog input/output PWM (*Pulse-width modulation*). In order to monitor the variations in each system; PV and Wind turbine separately, two different voltage circuits were built, installed before the load/charge controller.

Monitoring Solar Photovoltaic Panel

Voltage of photovoltaic panel

It was necessary to construct a voltage divider that works with a 0-35 Volt input and output and provides a range of 0-5 volt maximum and connected to the Arduino. To build the voltage divider, a mathematical relationship must be developed. This has to take into account the fact that the Arduino has 0 volts equal 0 bits and 5volts equal 1023 bits. Therefore, it is necessary to develop a mathematical relationship for the voltage divider and it is necessary to take this fact into account when building the divider.

The voltage divider used in this study is shown in Figure 9, and the mathematical relationship developed is represented by equation (1).

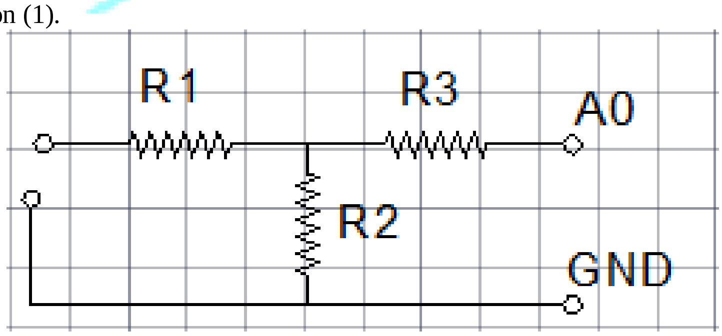

Figure 9. A voltage divider.

$$y = x * \frac{4.83}{1023} * A \quad (1)$$

Where:
R1=220kΩ
R2=2.2Ω
R3=1.9kΩ
Y=Amperage that will appear in Excel
X=The value read by the Arduino in points A0 and GND from voltage divider
A= A constant depends upon the divider functional dependence

The voltage divider is positioned parallel to the voltage source as seen in Figure.9; in this particular case it is placed at the entrance of the load/charge controller in order to obtain the exact value entering the driver. Figure 10 shows the form of connections of the voltage divider.

Current photovoltaic panel

In a system of photovoltaic panels, the voltage remains constant during the day and the current varies depending upon the solar radiation intensity (W/m2), in order to monitor a constant voltage and a current intensity variation, a circuit must be built to detect the current variation, and takes into account that the Arduino is fed current with a voltage in the range of 0-5 volts. Also, it must be also taken into account that the current of the solar panel is high, since it varies from 0.0 A to 7.14 A for solar radiation range from $0 \; to \; 1000 \; W/m^2$. It was observed during the testing that this can be represented by a linear relationship. This linear relationship will be validated later in this paper with real collected data from the weather station HOBO and that are obtained manually after the Arduino. This linear relationship that represents the solar radiation intensity and the amperage of the photovoltaic panel has been developed and is shown in Figure 11

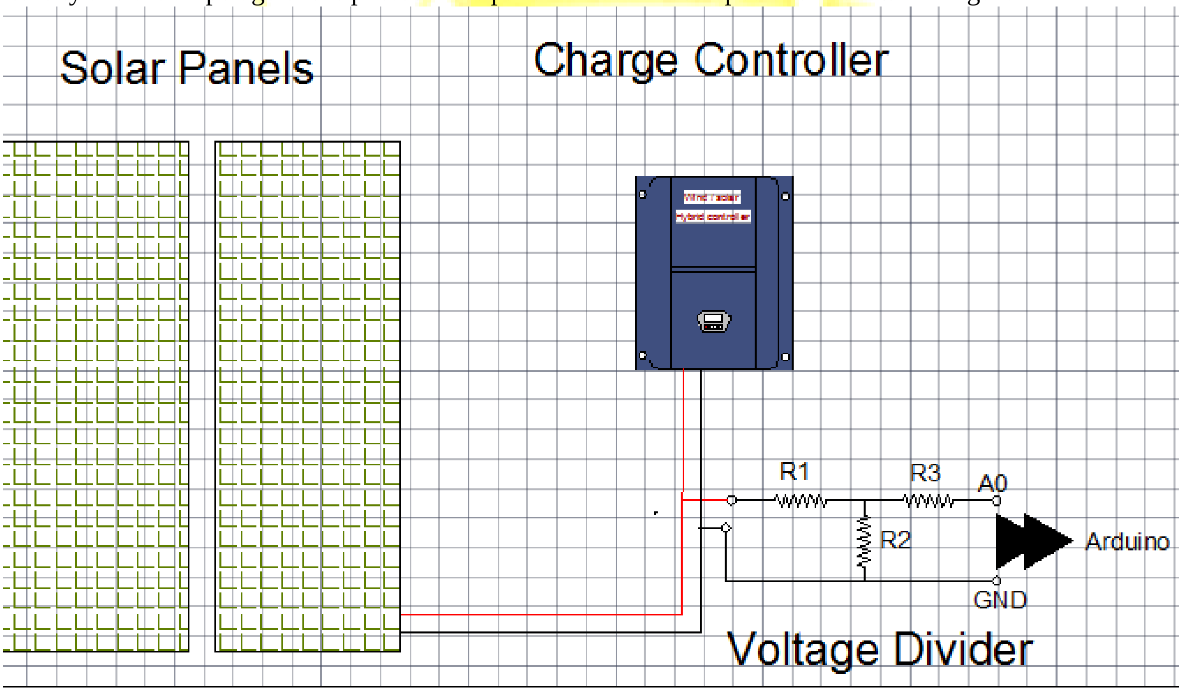

Figure. 10. A voltage divider connected in parallel before the charge controller.

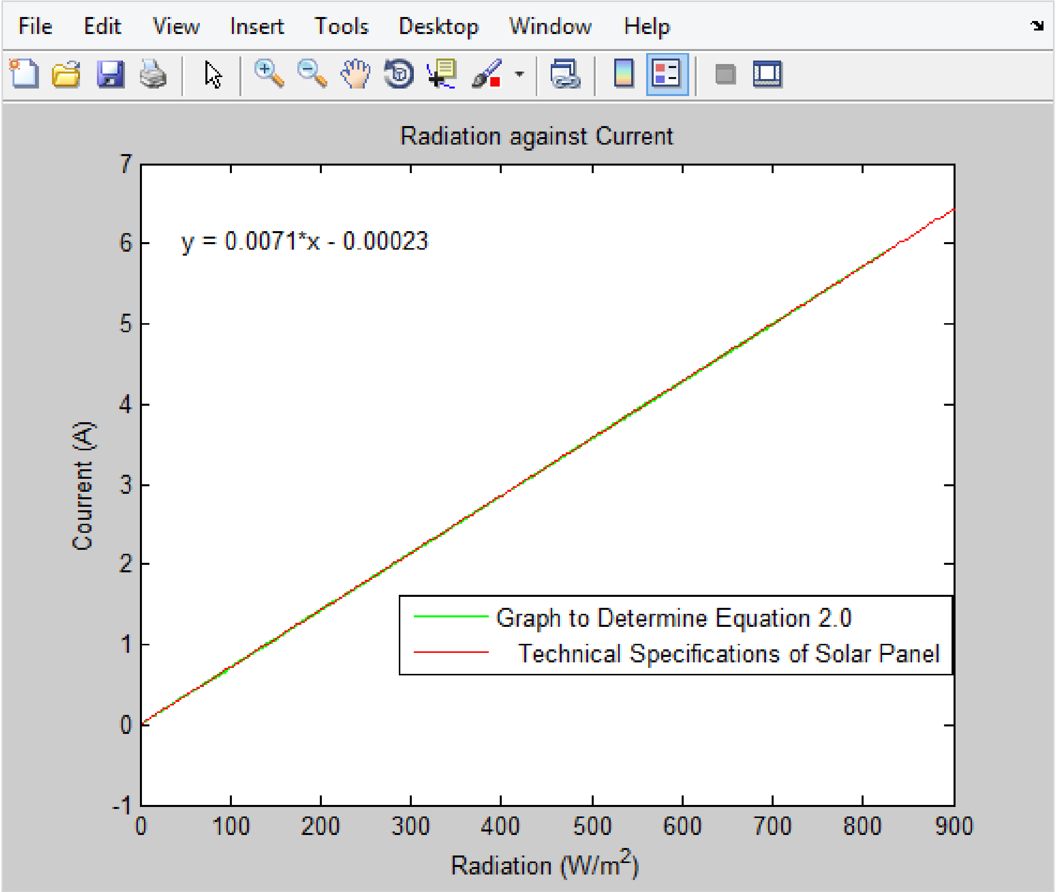

Figure 11.Tthe linear relationship between radiation and the amperage of the photovoltaic panels.

This developed equation shown in Figure.11 represents this linear relationship between solar radiation intensity and their respective amperage as follows:

$$A = R * 7.14 * 0.0023 \qquad (2)$$

Where:
A= Amperage.
R= radiation of the weather station HOBO recorded at every minute.

The graphical representation of the Equation 2 and shown in Figure.11 is called "*Solar Panel Operation Curve*".

The limits of solar radiation and Amperage of the solar panels are specified by the manufacturers of photovoltaic panels as presented in Tables .3 through 5. These tables also show the technical specifications of the panels that are employed in study.

Technical Data	
Type	SM636-12p,SM636-130W,SM636-140W
Type of Solar Cell	Mono-Cristaline 156mm*156mm
Number of Cell	36 pcs
Madule, Weigth	12 kg
Canector / Cross-Section	Cixi Renhe, TOP
Front Cover Glass	Cuztomizable
Front Cover Glass, Thickness	3.2 mm
Frame	Anodized Aluminium

Table 3: Specifications of Photovoltaic Panel

Electrical Data				
Maximum Power	*PMPP STC*	120W	130W	
Power Tolerance	*ΔSTC*	±2%	±2%	±2%
Maximum Power Voltage	*UMPP STC*	17.7 v	17.8 v	17.8 v
Maximum Power Courrent	*IMPP STC*	7.14 v	7.43 v	7.87 v
Open Circuit Courrent	*UOC STC*	21.7 v	21.8 v	22.1 v
Short Circuit Courrent	*ISC STC*	7.57 v	7.85 v	8.25 v
Module Efficiency	*ƞ STC*	12.10%	13.10%	14.10%
Maximun System Voltage	*UDC*	1000 v	1000 v	1000 v
STC: Irradiance 1000W/m^2 Spectrum AM 1.5 Cell Temperature 25°C Wind 0m/s				

Table 4: Electrical Specifications of Photovoltaic Panel

Temperature Coefficients		
Power Coefficient	*ακ (PMPP)*	-0.45%/*K*
Voltage Coefficient	*βκ (UCC)*	-0.35% /*K*
Courrent Coefficient	*φκ(ISC)*	0.065 ± 0.015% /*K*

Table 5: Temperature Specifications *of Photovoltaic Panel*

In order to determine the variation of the current intensity generated by the photovoltaic panel, it was necessary to determine the resistance that supports a high current as defined by the Ohm's law;

$V = I * R$

Where the voltage drop that is generated in that resistance, and this voltage drop enters to the Arduino.

It is assumed that the resistance is fixed at each current variation and this will result in variation of the voltage in the range of 0 to 5 volts as maximum value. To accomplish this, it was decided to disassemble a multimeter and remove its resistance “shunt”, because this particular multimeter design can support up to 10A of direct current (DC). The ohm value of this resistance is 0.12 Ω and it is compatible with the Arduino; in addition, it does not exceed 5volts for the analog input pins.

There the voltage can be calculated as follows;

$$V = I * R$$
$$V = 7.14A * 0.12\Omega$$
$$V = 0.857\text{V}$$

The data collected during the course of the experiments enable us to construct the curve shown in Figure 12. The voltage-dependent bits that shown in Figure 12, are the values read by the Arduino, each bit value is associated with their respective amperage value that was collected manually at every time the Arduino collects the data of the “shunt” resistance.

The mathematical relationship displayed in Figure.12, represents the shunt resistance; where X is the value of the bits read by the Arduino, and Y represents the amperage that can be displayed in Excel format.

The relationship between bits and voltage that is represented by the curve displayed in Figure 13, where the voltage values shown in this figure are the values collected manually at every time when the Arduino receives the bits of the shunt resistance. It can be seen from the results displayed in this figure that this relationship is nonlinear, and consequently can be represented by a nonlinear relationship as per equation (3).

The following equation represents the resistance shunt nonlinear relationship;

$$Y = p1 * x^8 + p2 * x^7 + p3 * x^6 + p4 * x^5 + p5 * x^4 + p6 * x^3 + p7 * x^2 + p8 * x + p9 \qquad (3)$$

Where:

P1= -0.000000066635
P2= 0.0000050125
P3= -0.0001573
P4= 0.0026676
P5= -0.026461
P6= 0.15508
P7= -0.51496

P8= 1.3646
P9= -0.043914

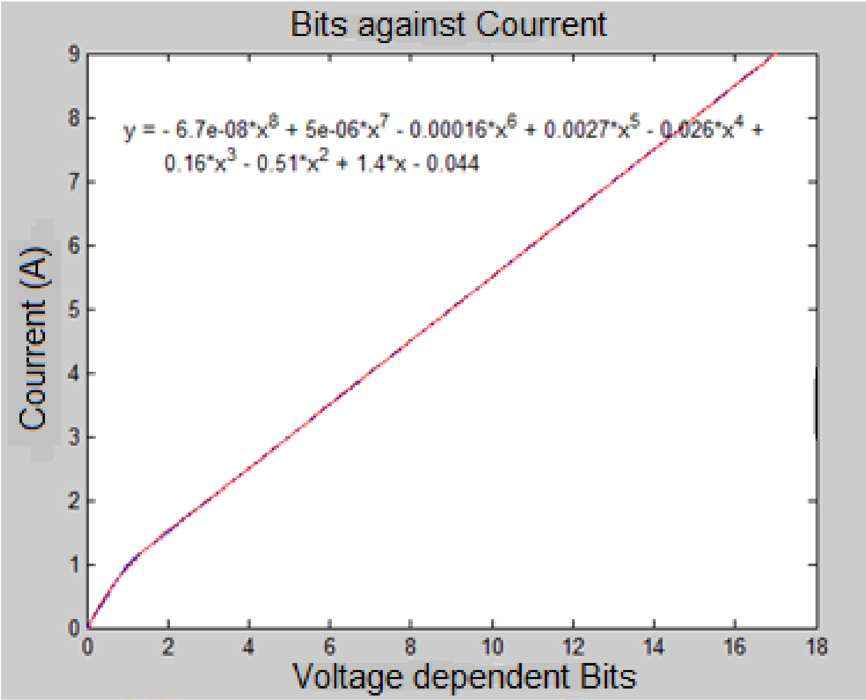

Figure 12. Data of voltage and amperage of Equation(3)

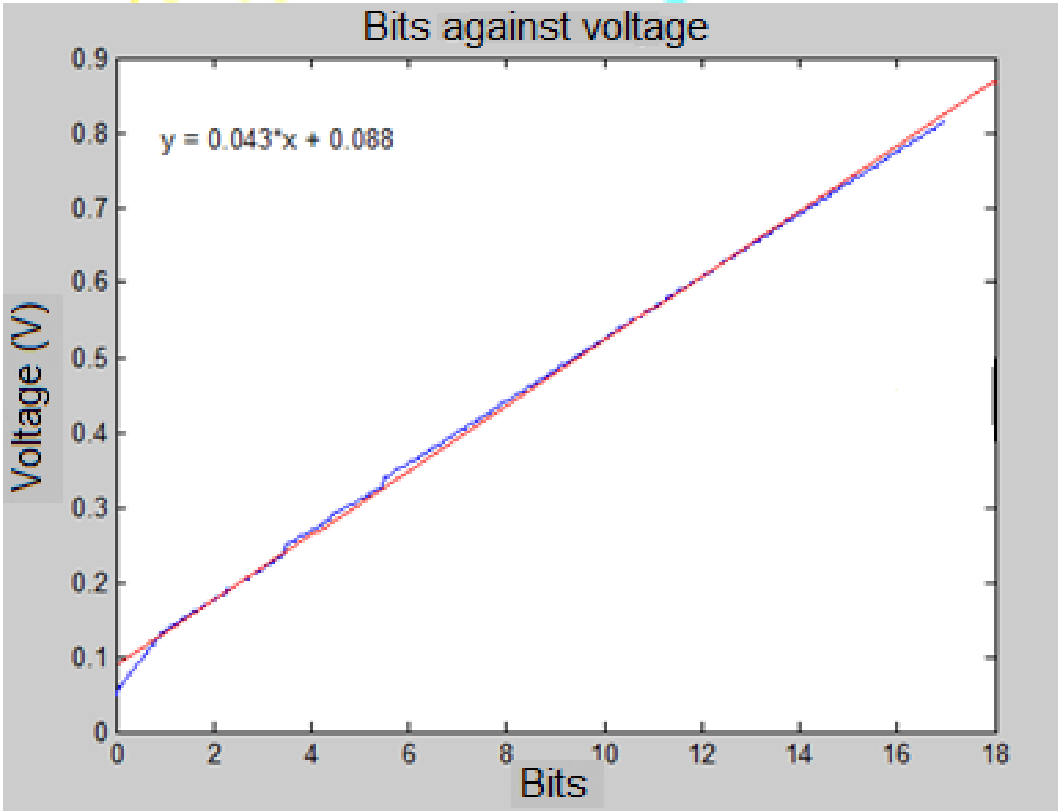

Figure 13. Voltage against bits to be able to determine the relationship between them.

It is worthwhile mentioning that to obtain the aforementioned data; a multimeter was placed in series with the load driver to record the intensity of the current with the help of the shunt resistance at the different conditions of the voltage drop. Figure 14 shows multimeter connected in series with the load driver.

Circuits for Wind Turbine

In order to construct the circuit's voltage and amperage sensors for measuring the voltage and current of the wind turbine, it was necessary to take into account that the current the wind turbine generates alternating current (AC), which is different from that of photovoltaic panel.

The technical specifications of the wind turbine are provided in table.1 and 2 as well as Figure., It can be seen from these specifications that a minimum wind speed of 2.5m/s is required to generate electric power with a voltage and current which is a dependent variable on the rotation speed of the blades and the generator. It is assumed that generator is asynchronous one, which has a frequency that depends on the speed of the rotor and the blades of the wind turbine. Therefore, in order to connect to the Arduino, it is necessary to rectify the voltage of the generator to the load/charge controller.

Voltage of Wind Turbine

The construction of the voltage rectifier consists of a Gretz bridge together with a stage of filtering and a voltage divider. The voltage input to the rectifier is 60 volts AC and the exit after the voltage divider is 5 volts DC, respectively. Figure 15 shows the rectifier and their respective electronic components.

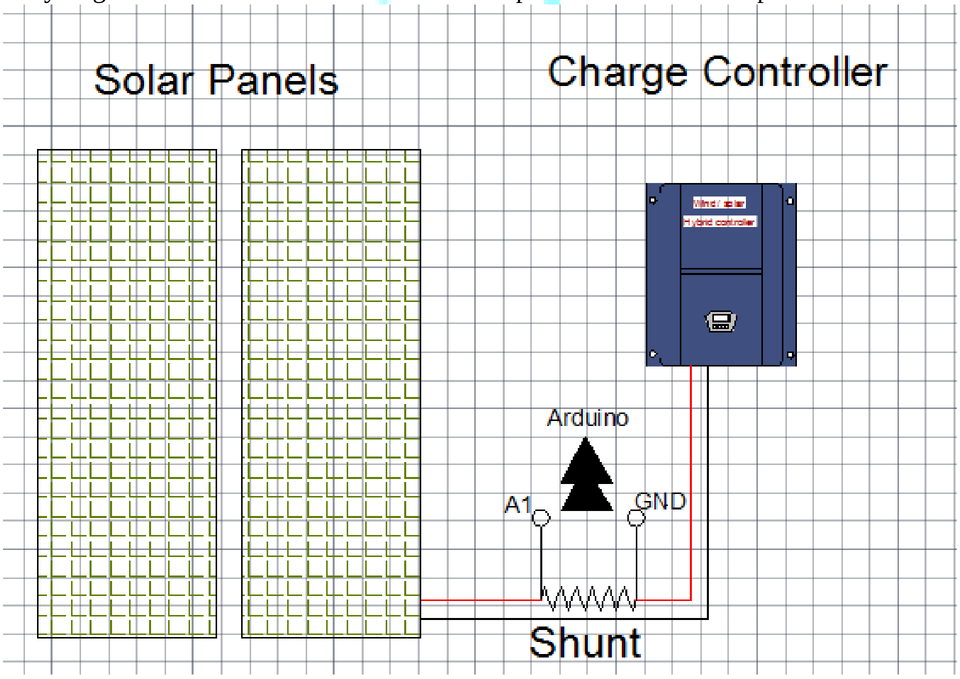

Figure 14. Multimeter connected in serie.

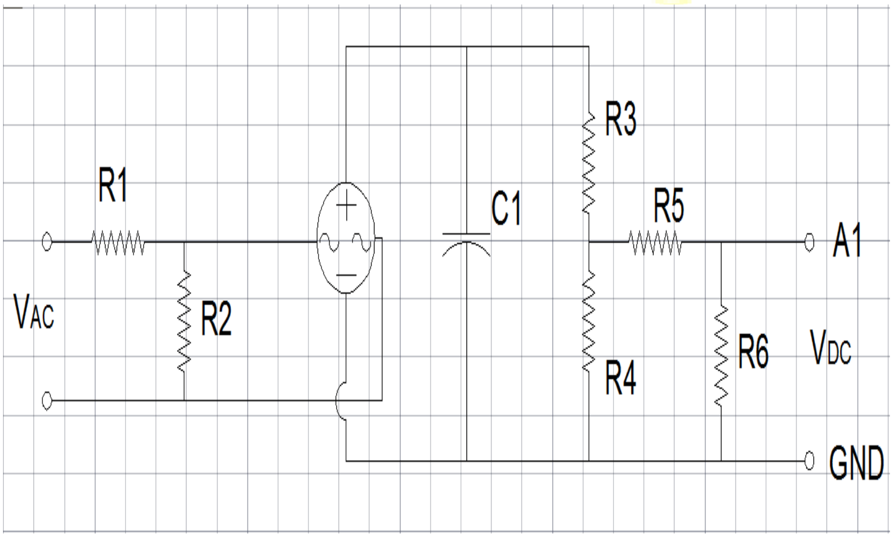

Figure.15. Voltage rectifier AC-DC

The following gives the different parameters presented for the rectifier in Figure.15:
3.9KΩ=R1, R2=10kΩ, R3=10kΩ, R4=10kΩ
R5=10kΩ
R6=2.2kΩ
C1=10*or*F

A mathematical equation has been developed to represent the rectifier presented in Figure.15, and can be written as follows;

$$y = \frac{50*x}{324} \qquad (4)$$

Where:
Y= value of voltage that appears in Excel.
X = value read by Arduino to the output of the rectifier.

Current of Wind Turbine

To measure the amperage of the wind turbine, a small transformer has been built that supports up to 15 A of alternating current (AC). This transformer is placed in series with the load controller where the current goes through. The primary winding of the transformer creates a magnetic flux that that induces a voltage to the primary winding and of equal frequency. It should be noted that the Arduino works with voltage input data with maximum 5 Volts (DC), therefore, it is important to determine the voltage generated by the amperage of the wind turbine when it passes through the transformer. This is the voltage that goes to the Arduino and is consequently stored in the database files. However, the voltage at the output of the secondary winding of the transformer remains AC; therefore, it is essential that a voltage rectifier be built that can be used by the Arduino. Figure 16 shows the rectifier circuit that was built and used at this stage for the data collection.

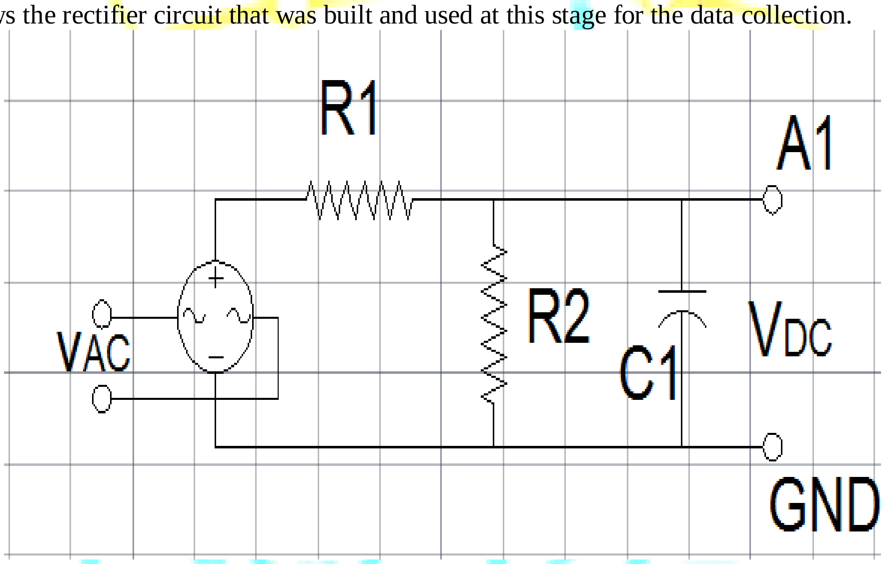

Figure 16. Voltage rectifier AC-DC

The following gives the parameters of the voltage rectifier outlined in Figure.16;
Where:
R1=47Ω/20Watts
R2=20Ω/20watts
C1=10*or*F

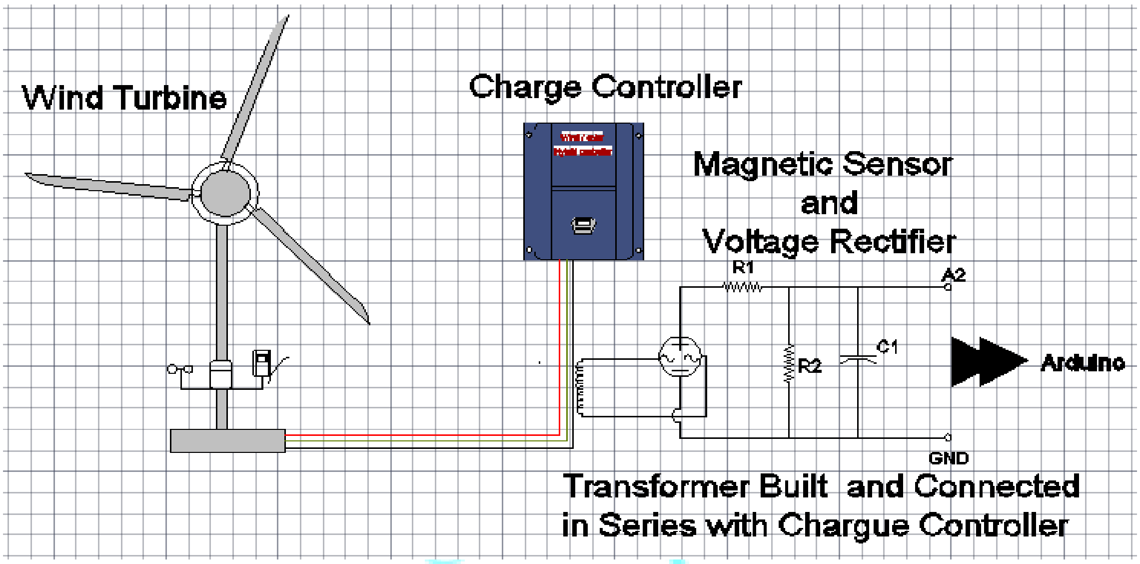

Figure 17. Transformer built in the laboratory connected in series to the charge controller.

Figure 17 shows the transformer with the rectification circuit displayed in Figure. 16. The mathematical equation representing the rectified output voltage of the transformer can be written as follows and the amperage will be stored in Excel format;

$$y = \frac{2.584 * x}{428} \quad (5)$$

Where:
Y= rectified output voltage of the transformer.
X= value read by Arduino of the rectified output of the transformer.

III. Results and Discussion

Voltage of photovoltaic panel

During the onset of the testing, several adjustments and tune ups have been made to the voltage divider equation, and were also calibrated in the following manner; a voltmeter is placed and connected to the charge/load controller input and gradually modified by the aforementioned equation to yield same value of the multimeter. Figure 18 shows the multimeter used during the calibration process of the voltage divider equation .The calibrated and adjusted voltage divider results are presented in Figure 19

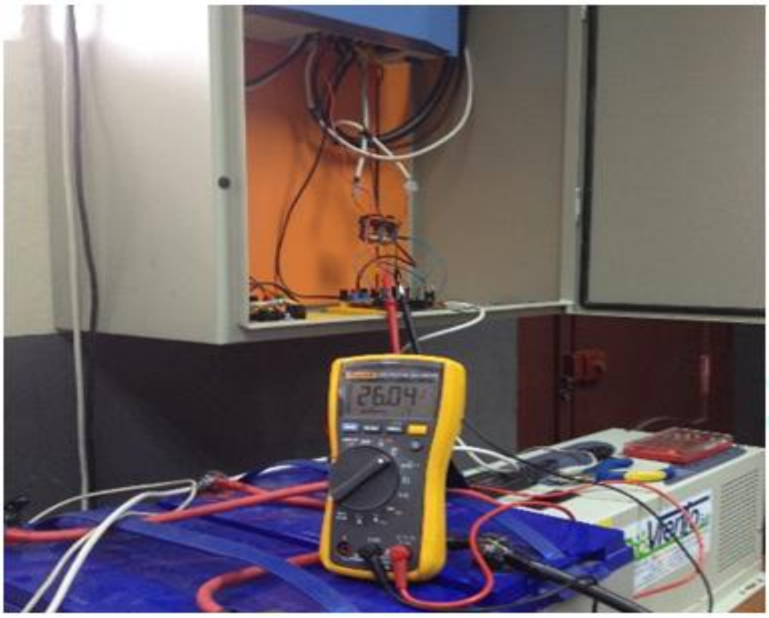

Figure 18. Voltmeter with which was calibrated the Equation (1.0)

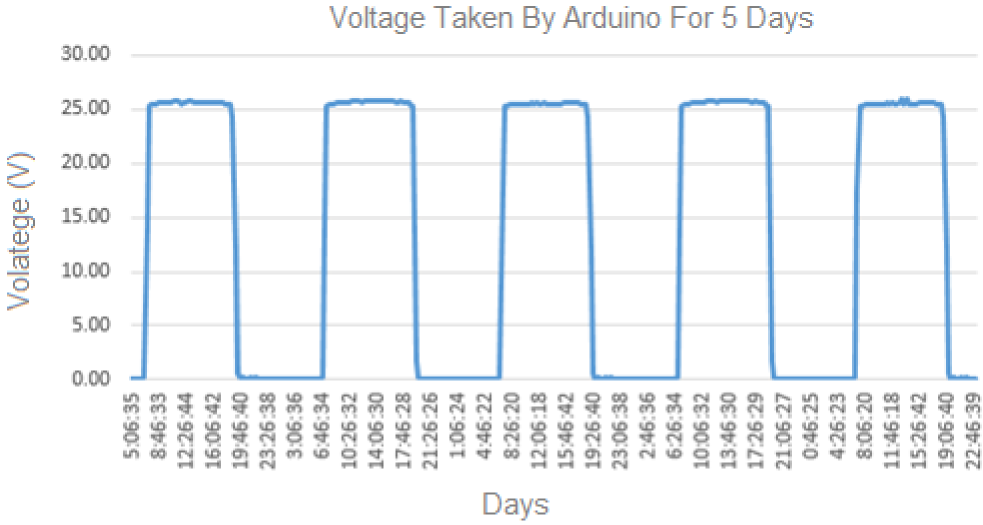

Figure 19. Voltage data taken with the Arduino during 5 consecutive days

It was noticed during the testing that the voltage of the photovoltaic panel does not vary during the day, however, slight variations were observed when the radiation exceeds $1000\,W/m^2$. In addition, it was also observed that the variations are insignificant. On the other hand, Figure 19 shows that the voltage divider can also be used to determine the efficiency of the photovoltaic panel with a minimum error in the voltage. This will be discussed later in this paper.

Current photovoltaic panel

The test of the multimeter showed that the amperage of the photovoltaic panel significantly varies during the day, and also varies with solar radiation. This may cause the data read by the Arduino to experience an error at each change of intensity of current that passes through the shunt resistance. A acceptable relative error has to be less than 10 %, therefore, repetitive tests were required and conducted in order to minimize the measurement error. The tests were conducted each day of the month with relative success, and it was possible to establish an error much less than 10 %. Figure 20 shows the data of the amperage collected manually after the multimeter measurements and it can be seen that the data has linear relationship with the radiation and amperage as calculated by Equation (2). On the other hand, Figure 21 also shows the solar panel operation curve and the green line represents the data obtained manually.

It can also be observed from figure .21 that data collected manually is fairly represented by equation (2). Therefore, we feel strongly that equation (2) can be considered as a reference to determine the relative error of each measurement data collected by the Arduino.

In the following, a sample is given for the calculation of the relative error between the data shown in Figure.21 which is presented and illustrated in Figure 20. The relative error between results calculated by equation (2) and the manual data is presented in Figure.21. It is worthwhile noting that the data collected by the Arduino shown in Figure.22 compared fairly with the data calculated by equation (2).

In the following sample of the relative error calculation is presented;

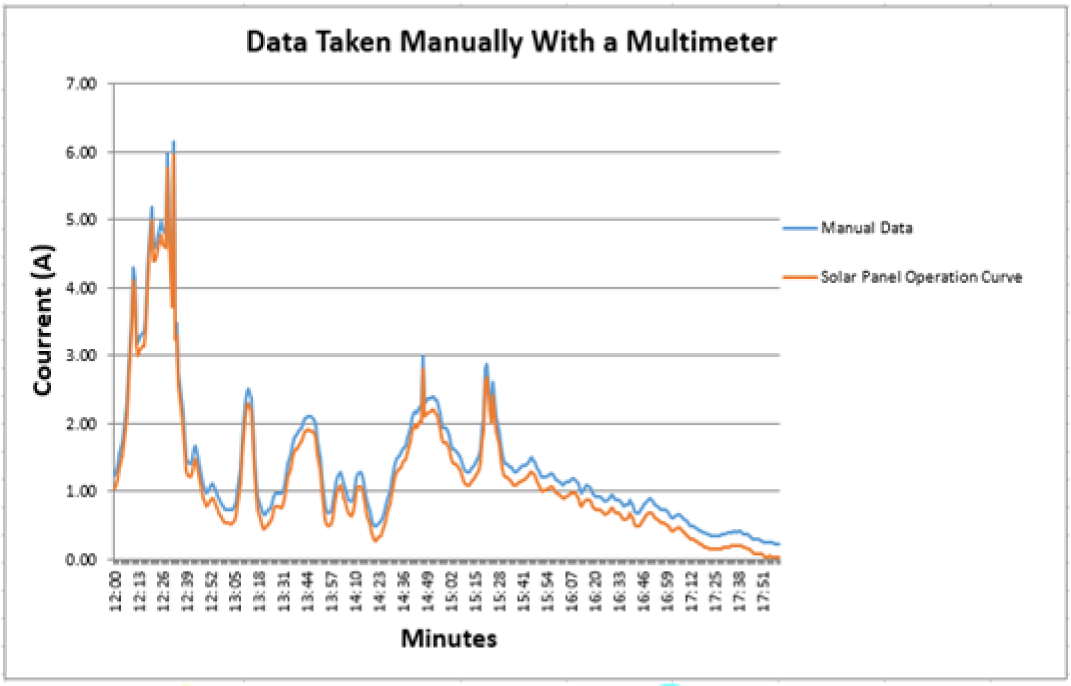

Figure 20. Solar panel operation curve and manual data

Average Data Equation (2) = 1.19 to
Manual Data Average = 1.4 to

Er= $\frac{1.4-1.19}{1.19} * 100$
Er=18.63%

Figure 23 presents the solar panel operation curve where the red line represents the solar panel operation curve and the blue line represents the data collected by the Arduino.

It can be observed from the data collected by the Arduino from the shunt resistance as shown in Figure 23 that there is a fair in agreement between the results calculated by Equation (2) and the data collected manually as per Figure 19. This also clearly shows that, the error is less than the error presented in Figure 19. Therefore, it can be concluded that Equation (2) can be considered as a reference for predicting the photovoltaic panel current as a function of the solar radiation.

The following is a sample calculation of the relative error between results and Arduino data presented in Figure 21 and Figure.23;

Average Formula Data= 1.19 to
Average Data Arduino= 1.24 to

Er= $\frac{1.24-1.19}{1.19} * 100$
Er=4.10%

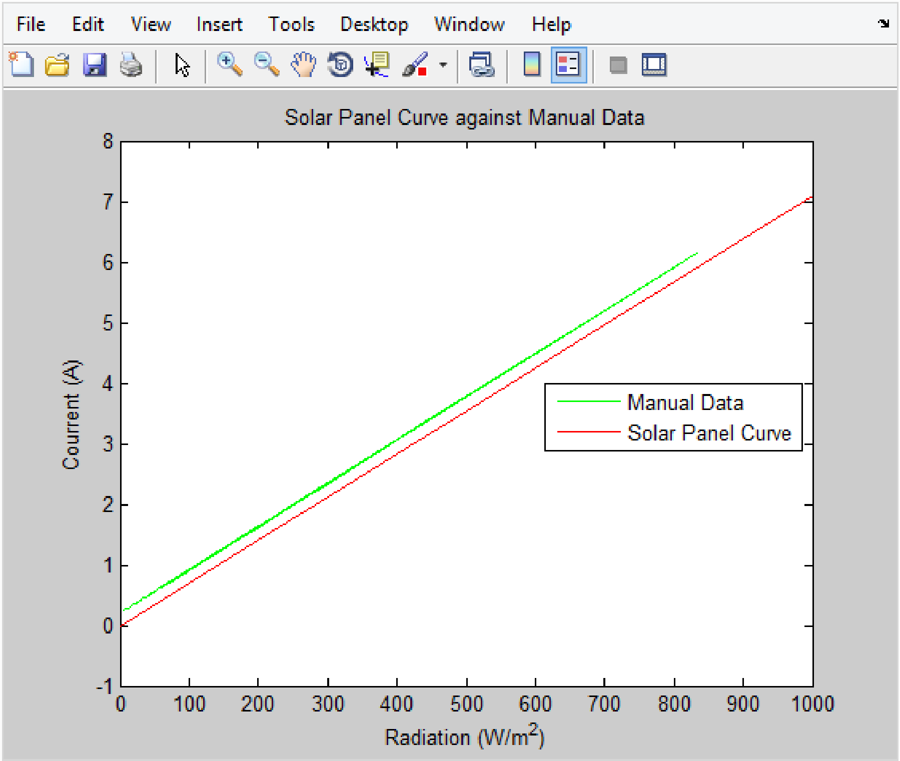

Figure 21. The red line represents the solar panel operation curve and the green line the data manually, respectively

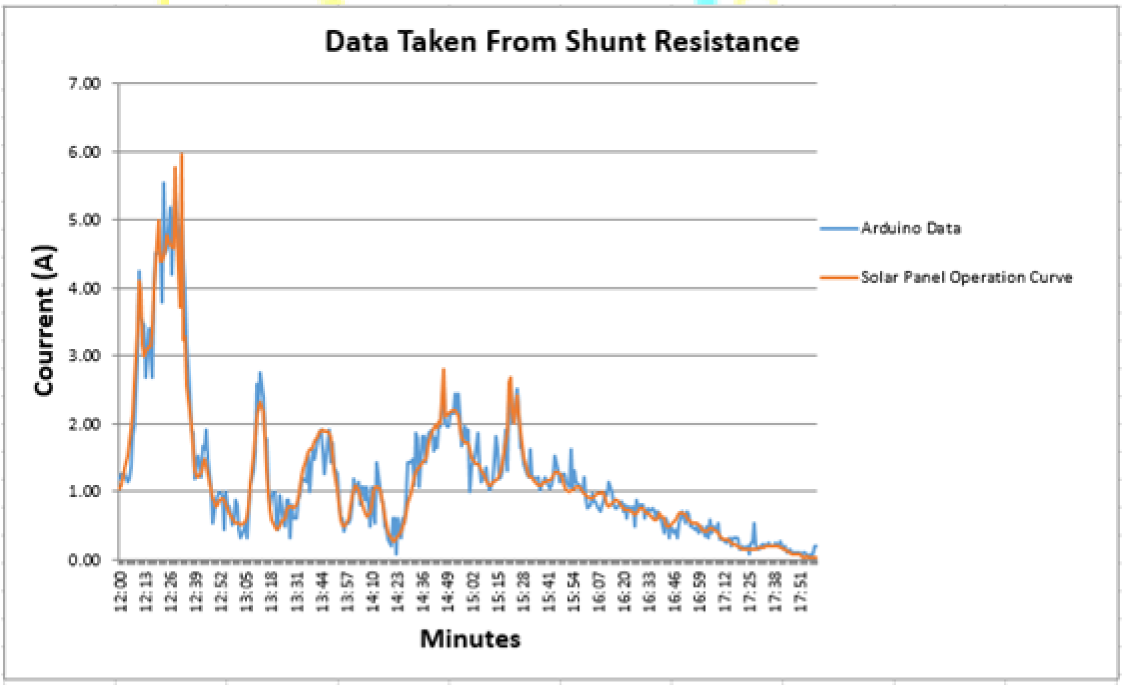

Figure 22. Data of solar panel operation curve and Arduino data .

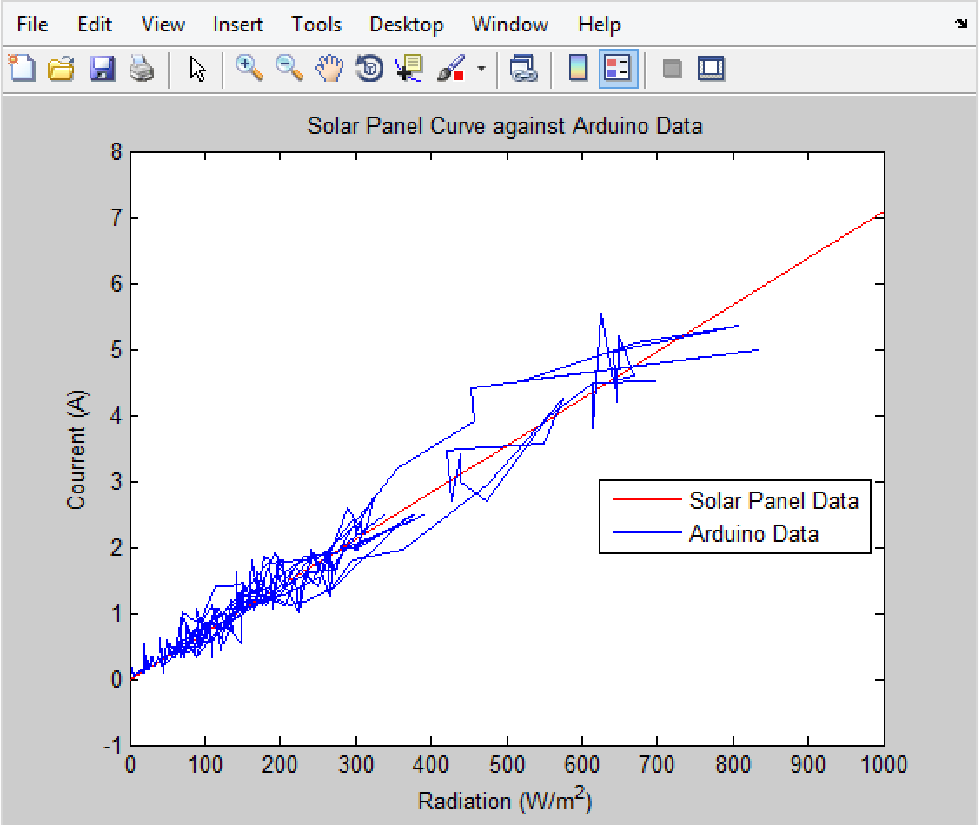

Figure 23. The red line represents the solar panel operation curve and the blue line represents the data taken with the Arduino.

Voltage of Wind Turbine

The input data AC voltage to the rectifier, values of DC output of the rectifier and voltage already stored in Excel spread sheet are presented in Table 5..

Input voltage AC	Output DC Voltage	Bits of DC voltaje	The voltage value Excel
0	0	0	0
5	0.47	36.93	5.7
10	0.84	66.09	10.2
15	1.27	99.14	15.3
20	1.68	188.95	20.2
25	2.12	165.24	25.5
30	2.56	199.58	30.8
35	2.96	230.68	35.6
40	3.37	262.44	40.5
45	3.76	292.89	45.2
50	4.17	325.94	50.3
55	4.63	360.28	55.6
60	4.98	387.50	59.8

Table 5. Displays all the values of voltage, bits belonging to the DC voltage and voltage values that will appear in Excel sheet.

The following gives a sample calculation of the relative error between input data of AC voltage and voltage value data as presented in Table 5;

Average Voltage Input AC = 30 V
Average value of Voltage Excel = 30,362 V

$$Er = \frac{30.362 - 30}{30} * 100$$

Er=1,205%

Current of Wind Turbine

Table. 6 displays the results of the several tests data carried out in the laboratory using variable voltage of 6 Volts AC and 0-120 incandescent bulbs of 100 watts electrical load each. It is worthwhile mentioning that at each single test, the data collected by the multimeter has been for a total the load was 600 Watts connected in series with the transformer-multimeter.

Input voltage AC (V)	Output DC Voltage (V)	Bits of DC voltage (V)	Data Real Of Amperage (A)	Amperage Value Excel (A)	Power AC (W)
0	0	0	0	0	0
5	0.49	100	0.82	0.65	3.25
10	0.76	155	1.02	0.92	9.2
15	0.93	189	1.16	1.08	16.2
20	1.09	223	1.30	1.23	24.6
25	1.25	255	1.43	1.41	35.25
30	1.37	280	1.56	1.55	46.5
35	1.50	306	1.67	1.68	58.8
40	1.65	338	1.79	1.77	70.8
45	1.76	362	1.91	1.95	87.75
50	1.85	378	2.03	2.06	103
55	1.95	400	2.12	2.19	120.4
60	2.09	429	2.21	2.22	133.2

Table 6. Displays all the values of voltage, bits belonging to the DC voltage and amperage values that will appear in Excel

The following gives sample of the relative error calculation between actual data of amperage AC and amperage value data as per Table 6.
.
Average of actual data of Amperage = 1,585 to
Average Amperage Excel Data = 1,559 to

$$Er = \frac{1.559 - 1.585}{1.585} * 100$$

Er=1.63%

On the other hand, samples of the temporal variations of the Photovoltaic solar panels data of the current, power and efficiency obtained experimentally by the aforementioned measuring system technique , in addition to solar radiations recorded by the Hobo measuring station are displayed in Figures 24 through 27. This experimental data has been used to validate Equation (2) as previously discussed. It can be also observed from the data displayed in the aforementioned figures, that the higher the solar radiation the higher the solar panels current, power output and efficiency. As demonstrated in the aforementioned sections, the relative error is 4.16 % with Equation (2), and this equation can be used to predict this data with great confidence.

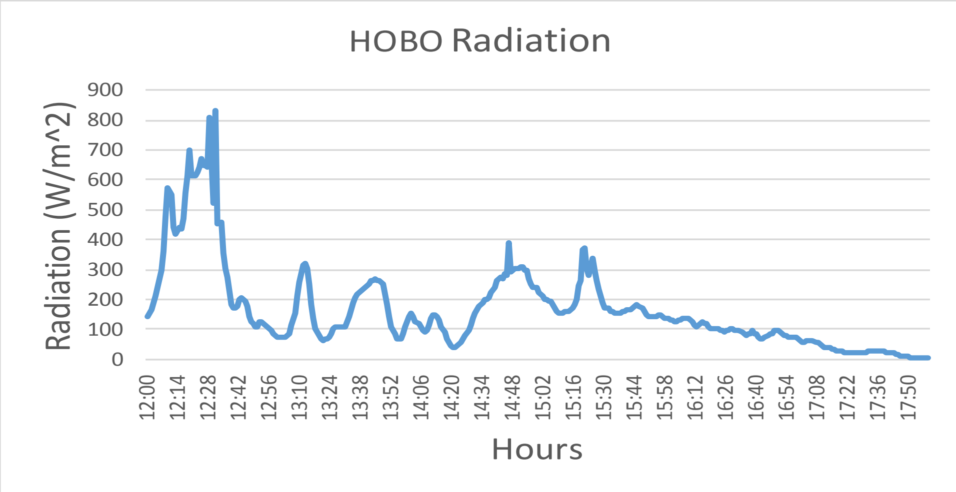

Figure. 24. The solar radiation variation during the testing.

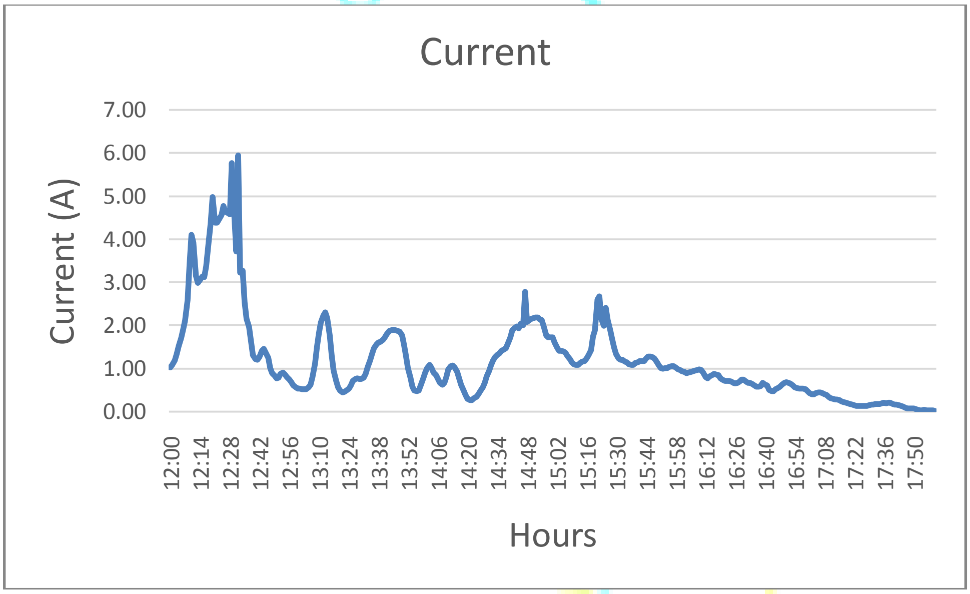

Figure 25. Current variation during the testing.

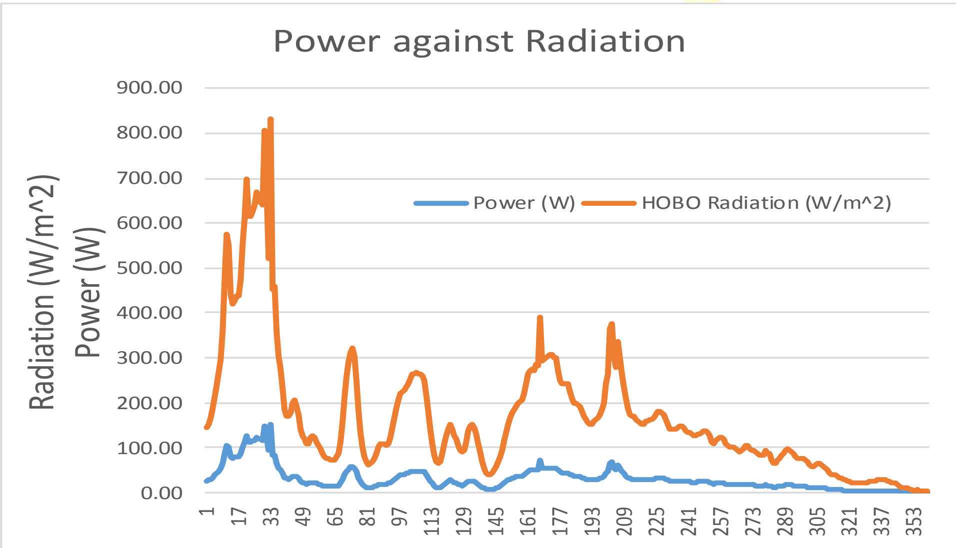

Figure.26. Power and solar radiation variation

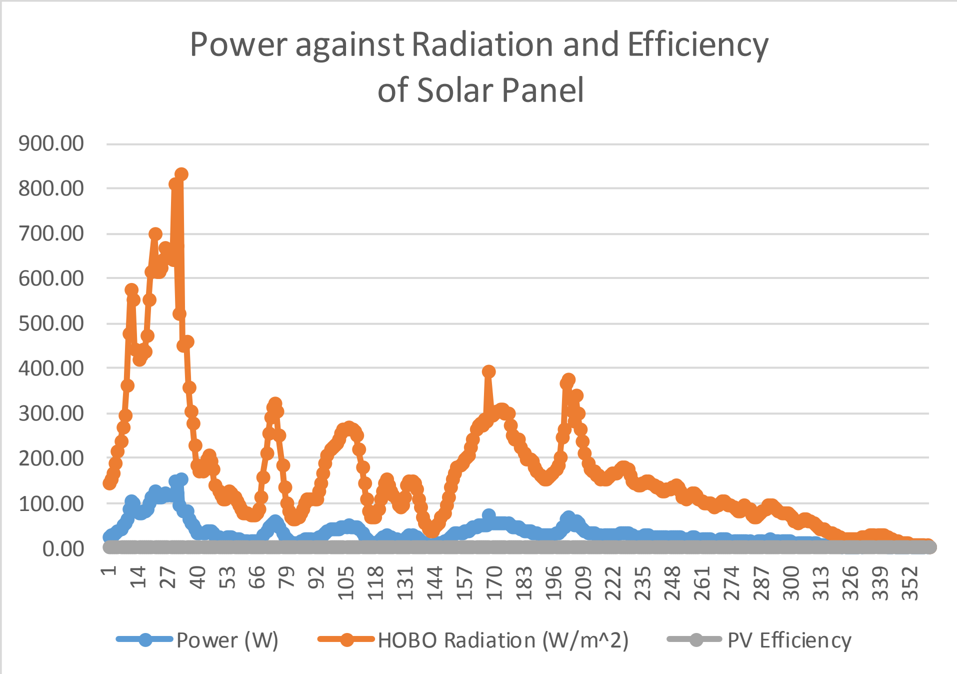

Figure. 27. Solar Radiation, Power and PV efficiency variation during testing

IV. Conclusions

This study presents the construction and implementation of a measuring system technique for the amperage and voltage of a hybrid system composed of photovoltaic solar-wind turbine, to evaluate the performance, power and efficiency. The basis of the development of the measuring system is the use of an Arduino Mega 2560 for interaction between the individual output of the solar photovoltaic, wind turbine and the data storage files. Relationships have been developed to determine the current, voltage of each individual system and consequently power, based upon the data collected through the Arduino. Validation of the data collected showed that the developed relationship predicted fairly the current and voltage of each system. The proposed technique for power measurements of AC and DC proved to be reliable and can predict numerically the amperage and voltage within relative error of 1.63 % for AC and 4.16% for DC, respectively.

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